



Searches for exotica at BABAR

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Abstract

Recent BABAR results for the search for lepton-number violating decay modes and the search for a dark photon are presented. 11 different lepton-number violating B decays have been analyzed and for the modes $B^+ \rightarrow K^{*-} l^+ l'^+$, $B^+ \rightarrow K^{*-} l^+ l'^+$, and $B^+ \rightarrow \rho^- l^+ l'^+$, with l and l' being either an electron or muon, the previous upper limits on the branching fractions are improved by an order of magnitude. The search for a dark photon A' is presented using a mass range $0.02 \text{ GeV}/c^2 < m_{A'} < 10 \text{ GeV}/c^2$. Previous constraints on the mixing strength ϵ obtained by other experiments are significantly improved in the presented analysis. Upper limits on ϵ are set at the level of 10^{-4} to 10^{-3} . The presented result excludes almost all of the remaining parameter space favored by explaining the discrepancy between the measured and calculated $(g-2)_\mu$ with a dark photon coupling.

Keywords: dark photon, dark matter, lepton number violation, new physics, Babar

1. The BABAR experiment and the BABAR data set

The BABAR collaboration took data with the BABAR detector [1][2] at the PEP-II asymmetric-energy e^+e^- collider at SLAC at different center-of-mass energies. During the data taking periods from 1999 to 2008, data has been taken at center-of-mass energies corresponding to [3]:

- the $\Upsilon(4S)$ mass: 424 fb^{-1}
- the $\Upsilon(3S)$ mass: 24 fb^{-1}
- the $\Upsilon(2S)$ mass: 14 fb^{-1}
- masses between the $b\bar{b}$ resonances: 48 fb^{-1} .

The data taken at the $\Upsilon(4S)$ resonance corresponds to $471 \times 10^6 B\bar{B}$ pairs.

2. Search for lepton-number violating processes in $B^+ \rightarrow X^- l^+ l'^-$ [4]

In this analysis we search for lepton-number violating (LNV) processes which are required to explain the

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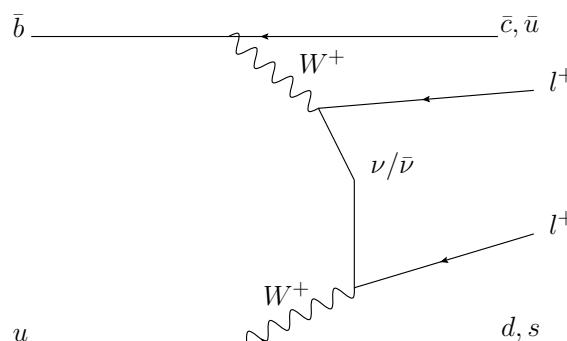


Figure 1: Possible LNV process in B -decays involving Majorana-type neutrinos.

matter-antimatter asymmetry in the universe. Due to the observed neutrino oscillations, we know today that neutrinos have a mass and Majorana-type neutrinos could make LNV processes possible (Fig.1). To search for such decays we study the following decay modes, in-

cluding the charge-conjugated modes:

$$\begin{aligned}
 B^+ &\rightarrow K^{*-} e^+ e^+ & B^+ &\rightarrow D^- e^+ e^+ \\
 B^+ &\rightarrow K^{*-} e^+ \mu^+ & B^+ &\rightarrow D^- e^+ \mu^+ \\
 B^+ &\rightarrow K^{*-} \mu^+ \mu^+ & B^+ &\rightarrow D^- \mu^+ \mu^+ \\
 \\
 B^+ &\rightarrow \rho^- e^+ e^+ & B^+ &\rightarrow K^- e^+ \mu^+ \\
 B^+ &\rightarrow \rho^- e^+ \mu^+ & B^+ &\rightarrow \pi^- e^+ \mu^+ \\
 B^+ &\rightarrow \rho^- \mu^+ \mu^+ & &
 \end{aligned} \tag{1}$$

The modes $B^+ \rightarrow K^- e^+ e^+$, $B^+ \rightarrow K^- \mu^+ \mu^+$, $B^+ \rightarrow \pi^- e^+ e^+$, and $B^+ \rightarrow \pi^- \mu^+ \mu^+$ have been analyzed by *BABAR* before [5] and have been used in this analysis for a crosscheck only. The results are found to be consistent with the previous *BABAR* analysis.

To select signal candidates, particle identification is used for all tracks and a boosted decision tree (BDT) discriminant is used to suppress background. Different momentum requirements are made on the lepton tracks and electrons and positrons from photon conversions are removed. To select intermediate states, we use the following modes:

$$\begin{aligned}
 K^{*-} &\rightarrow K_s^0 \pi^- \text{ and } K^{*-} \rightarrow K^- \pi^0 \\
 \rho^- &\rightarrow \pi^- \pi^0 \\
 D^- &\rightarrow K^+ \pi^- \pi^-
 \end{aligned} \tag{2}$$

with usual requirements like selections on the invariant mass or the flight length of the different intermediate states. A kinematic vertex fit is used for the B candidate and if more than one B candidate is found in an event then only the one with the highest fit probability is used further. More detailed information can be found in the journal article [4].

The signal extraction is done using a multidimensional maximum Likelihood fit in ΔE , m_{ES} , and the BDT output. For modes with intermediate states, the invariant intermediate state mass is also included in this fit. For all fits to data, the signal shape parameters are fixed to what was obtained from fits to Monte Carlo distributions. As an example, the fit projections on m_{ES} , ΔE , and the BDT output for the decay mode $B^+ \rightarrow \pi^- e^+ \mu^+$ can be found in Figure 2.

Since we don't see a significant signal, we calculate upper limits (UL) for the different branching fractions (BF) at the 90% confidence level (CL). The results can be found in Table 1.

In conclusion, we studied 11 different LNV decay modes and set upper limits on their branching fractions. Most of these upper limits are a large improvement compared to previous results.

B decay mode	UL for the BF ($\times 10^{-7}$)	
	<i>BABAR</i> result (@90% CL)	previous results
$B^+ \rightarrow K^{*-} e^+ e^+$	4.0	28 (CLEO, @90% CL)
$B^+ \rightarrow K^{*-} e^+ \mu^+$	3.0	44 (CLEO, @90% CL)
$B^+ \rightarrow K^{*-} \mu^+ \mu^+$	5.9	83 (CLEO, @90% CL)
$B^+ \rightarrow \rho^- e^+ e^+$	1.7	26 (CLEO, @90% CL)
$B^+ \rightarrow \rho^- e^+ \mu^+$	4.7	33 (CLEO, @90% CL)
$B^+ \rightarrow \rho^- \mu^+ \mu^+$	4.2	50 (CLEO, @90% CL)
$B^+ \rightarrow D^- e^+ e^+$	26	26 (BELLE, @90% CL)
$B^+ \rightarrow D^- e^+ \mu^+$	21	18 (BELLE, @90% CL)
$B^+ \rightarrow D^- \mu^+ \mu^+$	17	6.9 (LHCb, @95% CL)
$B^+ \rightarrow K^- e^+ \mu^+$	1.6	20 (CLEO, @90% CL)
$B^+ \rightarrow \pi^- e^+ \mu^+$	1.5	13 (CLEO, @90% CL)

Table 1: Results on the branching fraction for all analyzed LNV decay modes together with previous results obtained by other experiments.

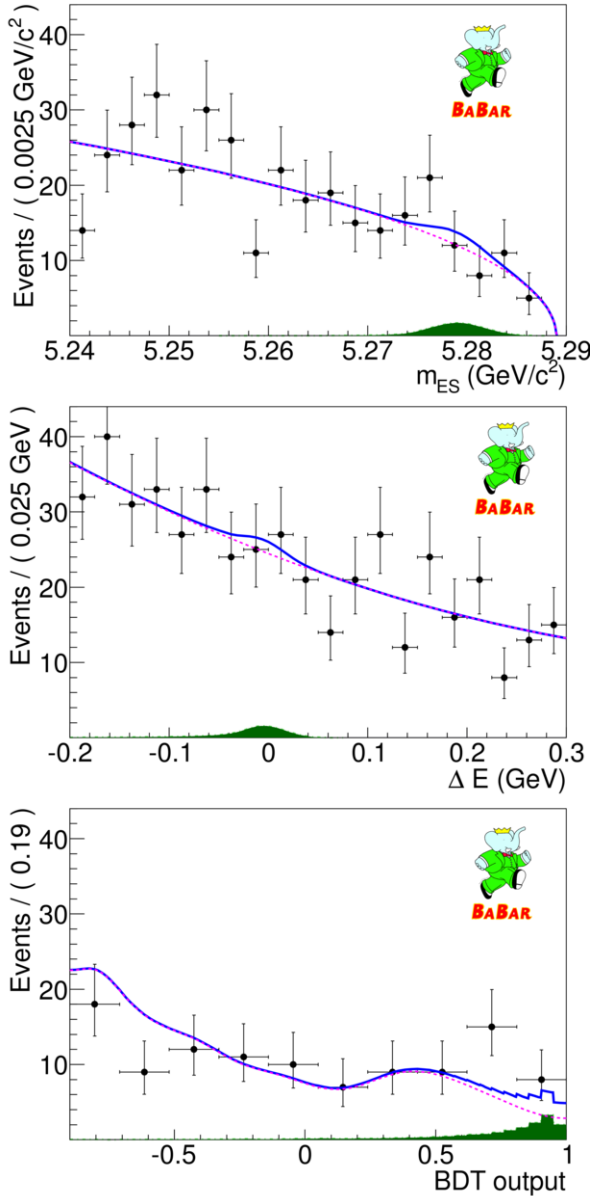


Figure 2: Fit projections on m_{ES} , ΔE , and the BDT output for $B^+ \rightarrow \pi^- e^+ \mu^+$ showing the combined signal+background fit (line), the background PDF (dashed line), and the signal PDF (solid histogram).

3. Search for a dark photon A' in $e^+e^- \rightarrow \gamma A'$, $A' \rightarrow e^+e^-, \mu^+\mu^-$ [6]

We know that dark matter is out there but the dark matter particles obviously don't interact much with the Standard Model (SM) particles. One New Physics scenario would be the introduction of a new $U(1)'$ with a corresponding dark photon A' that could couple to the SM hypercharge via kinetic mixing [7]. This introduces an effective interaction between the dark photon and the electromagnetic current proportional to $\epsilon e A'_\mu J^\mu_{EM}$, with the mixing strength ϵ . Such dark photons would mediate annihilation of dark matter particles into SM fermions [8, 9, 10]. In the observation of cosmic rays, it was found that there is an excess of positrons but lack of antiprotons [11, 12, 13]. If a dark photon as described before would be the reason for that then the mass of the A' should be in the range of $1 \text{ MeV}/c^2$ to about $2 \text{ GeV}/c^2$.

In this analysis, we search for a dark photon in the reaction $e^+e^- \rightarrow \gamma A'$ with $A' \rightarrow e^+e^-, \mu^+\mu^-$, which can probe for a dark photon with a mass in the range $20 \text{ MeV}/c^2 < m_{A'} < 10 \text{ GeV}/c^2$. To reconstruct this decay modes, events with 2 oppositely charged tracks and a single photon are preselected. A neural network is used to suppress the SM interaction $e^+e^- \rightarrow \gamma e^+e^-$ and particle identification is used for the charged tracks. A kinematic vertex fit is performed on the whole event with a beam-energy constraint. In the search for a dark photon, the invariant mass regions in m_{ll} consistent with a $\omega, \phi, J/\psi, \psi(2S), \Upsilon(2S)$, or $\Upsilon(3S)$ resonance are excluded.

To search for a signal, the invariant e^+e^- mass, $m_{e^+e^-}$, and the reduced combined muon mass, $M_R = \sqrt{m_{\mu^+\mu^-}^2 - 4m_\mu^2}$, are divided into intervals, each about 20σ to 30σ of the expected signal resolution in $m(A')$ wide. The expected signal resolution is between $1.5 \text{ MeV}/c^2$ and $8 \text{ MeV}/c^2$. In each interval a fit is performed while data taken at different beam energies are fitted separately and the final results are combined. This analysis makes use of all of the available BABAR data taken at all the different beam energies.

The cross section result from the fit together with the significance of the signal, $S_S = \sqrt{2 \log(\mathcal{L}/\mathcal{L}_0)}$, is shown in Fig.3 for the e^+e^- mode and in Fig.4 for the $\mu^+\mu^-$ mode. There is no significant signal observed and we derive from the cross section the upper limits on the mixing strength ϵ as a function of $m_{A'}$ shown in Fig. 5 together with the results obtained by other experiments. The result of the presented analysis also excludes most of the parameter space motivated by interpreting the discrepancy between the measured and calculated $(g-2)_\mu$ with such a dark photon interaction.

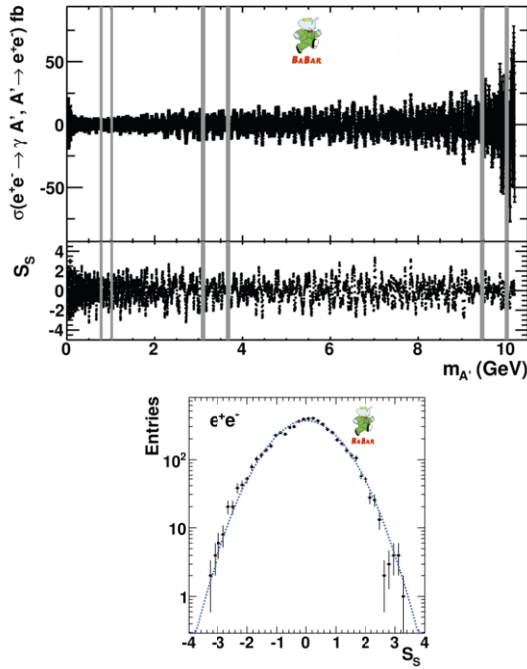


Figure 3: The $e^+e^- \rightarrow \gamma A', A' \rightarrow e^+e^-$ cross-section (top) together with their respective statistical significance (middle) as a function of the dark photon mass and the distribution of the statistical significance obtained from all fits (bottom, data points) together with the expected null hypothesis (bottom, dashed line).

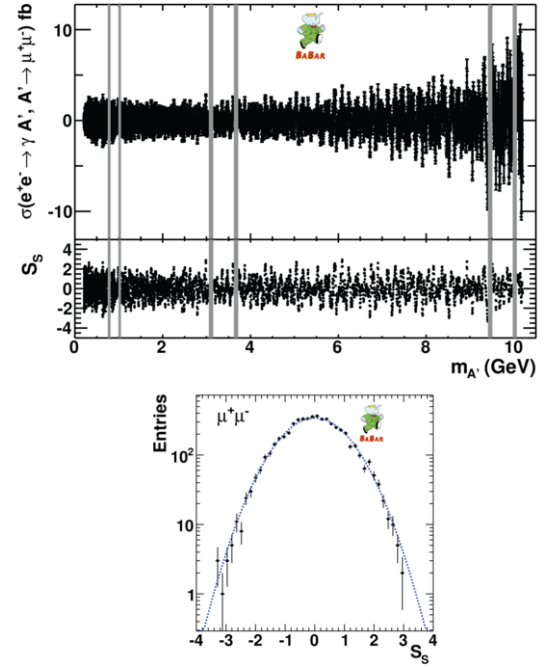


Figure 4: The $e^+e^- \rightarrow \gamma A', A' \rightarrow \mu^+\mu^-$ cross-section (top) together with their respective statistical significance (middle) as a function of the dark photon mass and the distribution of the statistical significance obtained from all fits (bottom, data points) together with the expected null hypothesis (bottom, dashed line).

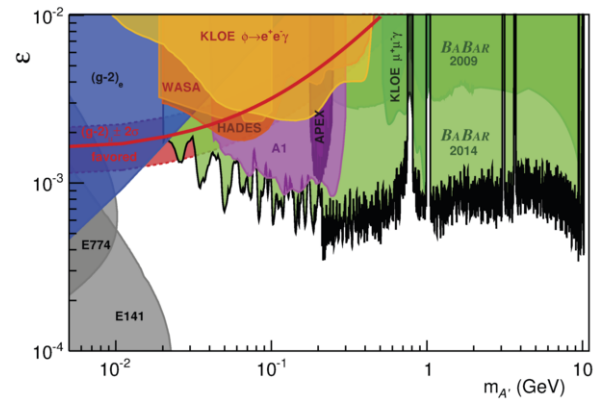


Figure 5: Upper limit at the 90% CL on the mixing strength ϵ as a function of the dark photon mass.

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